LA-UR -91-2846

LA-UR--91-2846

DE91 017828

TITLE: REVIEW OF THE HEAVY ION PHYSICS SESSIONS

AUTHOR(S): Barbara V. Jacak, P-2

MASTER

SUBMITTED TO: Proceedings, 4th Conference on the Intersections between Particle and Nuclear Physics, Tucson, Arizona, on May 24-29, 1991

Review of the Heavy Ion Physics Sessions

B. V. Jacak
Los Alamos National Laboratory, Los Alamos, NM 87545

INTRODUCTION

The parallel sessions on Heavy Ion Physics covered several areas of recent progress in characterizing the nuclear equation of state and the search for deconfined quark matter. Studies of systems from 1 to several hundred GeV/nucleon have been made in order to map the behavior of nuclear matter over a wide range of temperature and pressures. We have also considered results from proton-nucleus reactions in the heavy ion physics discussions. This should help untangle "nuclear effects" due to the presence of relatively undisturbed nuclear matter from observables arising in the hot, dense part of the system.

Even though heavy ion physics covers a large range of bombarding energies, the same two basic questions must be answered. The first problem is to characterize the system that has been produced. We need to determine the energy density, lifetime, temperature and baryon density reached in the collision before expansion and particle production. Then we may address the second issue and look for evidence of new physics. At this meeting, we heard new results from experiments, and theoretical analyses which strive to explain all available data, including those from proton-nucleus collisions. We explored heavy quark production, which may indicate quark matter through color screening of $c\bar{c}$ pairs. We heard new results in strangeness production, which has been predicted to be enhanced if quark matter is formed. There were also discussions of jets and minijets, which may probe the hot, dense matter existing early in the collision.

SOURCE SIZES FROM BOSE EINSTEIN INTERFEROMETRY

One of the promising ways to study the produced system is via the measurement of two particle correlations. Bose Einstein interferometry on pion pairs can yield information about the size and shape of the system emitting the pions and allow a better estimate of the energy density. Scott Pratt reminded us that final state interactions modify the measured correlation function, and corrections are necessary. For large sources, coulomb corrections increase the measured correlation by 5-10%, while for small sources, the strong interaction requires a correction, which decreases the correlation. The decay of resonances significantly reduces the correlation and modifies the shape of the correlation function. However, these effects are understood and can be corrected for.

Bill Zajc reviewed the current status of interferometry results in high energy p-p and p-nucleus collisions. He reminded us that all the extracted source radii are approximately 1 fm and imply a spherical source. However, he cautions that the data analysis varies greatly from one experiment to the next, without a consistent set of corrections. This will need to be addressed, particularly as high statistics data sets become available and we attempt more detailed analyses to extract the shape and time evolution of the source.

Nevertheless, we may take a first look at the dependence of the extracted source radii on the charged particle multiplicity in p-p, p-A and A-A collisions. Results from heavy ion collisions, presented by Richard Morse for the E802 collaboration, and p-p and $\alpha - \alpha$ collisions at the ISR suggest that the source radius grows as the square root of the multiplicity. This motivates an interpretation of the radius as the size of the system when the pions "freeze out" and no longer interact with one another. However, recent data from UA1, C0 and CDF for pp collisions are consistent with linear growth of the source radius wih charged particle rapidity density. Such a linear dependence would be expected in a boost- invariant system. Unfortunately the current experimental situation does not allow an unambiguous resolution of this difference. Systematic effects in the experiments and subsequent analyses must be much more carefully controlled. Richard Morse showed the importance of proper particle identification, two-track acceptance, and fitting procedures to the extracted values. We expect that the current set of dedicated experiments will provide the statistics and control of sytematics to settle this question.

Scott Pratt also pointed out that analysis of high-resolution, high statistics data may furnish considerable information about the lifetime of the source. This might indicate new physics if, for example, pions are emitted over a long time, as expected during a phase transition from quark matter to hadronic matter. Unfortunately, the decay of resonances also increases the apparent source lifetime, however this effect can be calculated and corrections made. The dependence of the lifetime on the pion energy may give information about cooling (and expansion) of the source, while the energy dependence of the source size may indicate collective expansion effects. The source size along the beam axis gives the velocity gradient, which is related to the energy density. The experiments currently underway should allow such analyses.

Jeff Wilkes for the EMU 01 collaboration reminded us that the search for intermittency in heavy ion collisions, which is a search for local density fluctuations, may also be sensitive to the two particle correlations arising from Bose Einstein statistics. In fact, the higher order moments of the multiplicity distributions are consistent with predictions from the second order moments, suggesting that the intermitteacy effect is dominated by two particle correlations. Such an effect was suggest for pp data by Carruthers and Sarcevic.

SOFT DILEPTONS AS PROBE OF HOT HADRONIC MATTER

Leptons provide a useful probe of hot hadronic matter despite their small formation cross sections because they are penetrating and relatively immune to rescattering effects. Consequently, they may tell about the early stages of the collision. In high energy nucleus nucleus collisions, thermal production of dileptons is of particular interest. At the Bevalac, dilepton production should also be sensitive to the density of the system. Other processes giving rise to leptons include bremsstrahlung, hadron decays, and pion annihilation, so the interpretation of experimental results requires theoretical control of all of these. Charles Gale discussed issues surrounding attempts to study the temperature and density of the early system via soft dileptons and specific effects on the spectra from modification of the pion dispersion relation in hot, dense matter.

Peter Seidl shewed dilepton spectra from the DLS collaboration for 1 and 4.9 GeV per nucleon heavy ion and p-nucleus collisions. In order to reproduce the p-Be data, it has been assumed that production of dileptons is dominated by hadronic bremsstrahlung. This may be tested by p-p and p-d collisions, and Seidl showed preliminary data from DLS on these systems. It was found that the production ratio of dileptons from deuterium and proton targets is approximately 2 at 1 and 4.9 GeV, in strong disagreement with the larger ratios predicted by bremsstrahlung dominance. These results may indicate that inelasticity in the collisions cause the dipole approximation used in the calculations to break down, or that bremsstrahlung is not the dominant effect at 4.9 GeV. When the calculations can quantitatively predict the results of the p-d collisions, we may then apply them with greater confidence to study the various contributions to dilepton spectra in nucleus-nucleus collisions.

BARYON FLOW AND RAPIDITY DENSITIES

Collective flow of baryons is of great interest at the Bevalac as the magnitude of the flow is determined by the nuclear equation of state, and was discussed by Declan Keane. At higher energies, the baryon rapidity distributions indicate how well the target stops the projectile and what fraction of the longitudinal energy of the beam is available as transverse energy. In fact, Peter Levai told us that collective flow of baryons may provide a signal for deconfinement in high energy collisions. This is because plasma formation would slow the decoupling of different mass particles from the collectively expanding system. Unfortunately, collective flow is difficult to measure as other effects also modify the charged particle transverse momentum distributions.

From proton and pion rapidity distributions measured for 60 GeV/nucleon O + Au collisions, Shaheen Tonse estimated that the beam loses approximately 80% of its energy. This is comparable to estimates of the stopping based on transverse energy measured calorimetrically. Using an event generator, ATTILA, which gives reasonable agreement with the data, he estimates that the collisions produce a system approximately 3 fm in extent with an energy density around 1 GeV fm^{-3}. The lifetime of this system is short, 1 fm/c. Net charge distributions from 100 GeV/c hadron nucleus collisions were presented by Lou Voyvodic. These data clearly provide a challenge to the nucleus nucleus event generators; the event generators must be shown to reproduce the hadron nucleus results before their predictions about energy densities and lifetimes reached in nucleus-nucleus collisions may be taken seriously.

We turn now from efforts to determine the size, shape, energy density, etc. of the hot dense system to studies of specific signals of new physics. Brian Bush reminded us that we must always check whether quark matter signals can be described by "known" physics. Before concluding that the language of quarks and gluons is appropriate to describe ultrarelativistic heavy ion collisions, Bush proposes that the data be compared to calculations in which nucleons interact through meson fields. If such a calculation, which is currently being prepared, can describe the global features of the heavy ion data, it will indicate that such observables cannot imply "new' physics.

HEAVY QUARK PRODUCTION

A joint session was held with Hadron Physics, addressing heavy quark production in both nucleus-nucleus and hadron-nucleus collisions. Matsui and Satz predicted that J/ψ production should be supressed in a quark-gluon plasma due to color screening of $c\bar{c}$ quark pairs. Suppression of J/ψ production was, in fact, observed in central nucleus-nucleus collisions by experiment NA38 at CERN. The suppression was largest for low transverse momenta, as predicted for color screening. However, nuclear effects on J/ψ production have also been observed in hadron-nucleus collisions, and it is necessary to describe both systems with a consistent theory.

Ramona Vogt and Sean Gavin reviewed the status of theoretical descriptions of J/ψ production. Both used models incorporating nuclear absorption and dense matter effects on the bound $c\bar{c}$ pair. Gavin focussed on the p_t dependence of J/ψ suppression, while Vogt looked at the x_f distributions observed in p nucleus collisions.

Gavin reminded us of the need for a unified theoretical description of the A and p_t dependence of J/ψ in p A and A A collisions. He notes that in p nucleus collisions, J/ψ and Drell Yan have very similar p_t dependences. This implies that initial state scattering, which broadens the parton p_t distribution, is important for the p_t dependence of the production cross section. Combining the data from NA3, NA10 and E772 suggests that the p_t kick may increase with larger q^2 and decrease with larger $\sqrt{s}$. Comparing these data with heavy ion results from NA38 shows rather good agreement in shape and suggests a common source of J/ψ suppression in all cases. In addition to initial state scattering, the J/ψ may be dissociated by nuclear absorption, secondary scattering with comoving partons, or perhaps plasma screeing. A quantitative comparison of the heavy ion data with a model which fits p nucleus results is not yet conclusive. The data are not fully described by the known effects, but the difference is at the level of one standard deviation. A higher statistics measurement is required to determine whether a contribution from screening in a plasma is present, these data are currently being collected at CERN

Vogt focussed on understanding the observed x_f dependence of J/ψ pro duction in proton-nucleus collisions. When the nuclear dependence is parameterized as $\sigma_{hA \to \psi} = \sigma_{hN \to \psi} A^{\alpha}$, it is found that α decreases by 30% between $0 < x_f < 1$. The combined x_f and A dependence may be described by a parton fusion model incorporating nuclear absorption, comover scattering and low x_f shadowing. At large x_f, intrinsic heavy quark states in the projectile wavefunction must be included at a level around 1% to describe the data. For $x_f < 0$, there is an additional strong absorption effect that is not yet understood.

Denis Jouan reviewed the status of the NA38 results. He showed new data on proton-nucleus collisions, and fits to extract the A^{α} dependence together with the heavy ion data for O + U and S + U collisions. Preliminary values of $\alpha = 0.91$ for J/ψ and $\alpha = 1$ for Drell-Yan confirm the earlier conclusion the J/ψ production is suppressed in central nucleus- nucleus collisions. Fitting the J/ψ data as a function of the number of nucleon-nucleon collisions yields a reasonable fit to all the data with an α value of 0.89. This is in reasonable agreement with values extracted from p-nucleus collisions by other groups.

The dimuon spectrometer of NA38 also measures ϕ and $\rho - \omega$ meson production in nucleus-nucleus collisions. The ratio $\phi/(\rho + \omega)$ increases by a factor of 3, in central compared to peripheral collisions. This was shown to be due to enhanced ϕ production, rather than a suppression of ρ and ω. In p-U collisions the effect is much smaller, and also for high p_t ϕ mesons. A theoretical analysis of this result follows below, in the section on strangeness production.

Andrzej Zieminski presented new results from Fermilab experiment E672/706 on hadron + Be and Cu, for J/ψ and ϕ production. ϕ mesons are produced at more central rapidities than J/ψ. $\alpha = 0.76$, 0.81 and 0.87 for $\rho/\omega, \phi$ and J/ψ, respectively. The E772 result, $\alpha = 0.92$ for the J/ψ, agrees reasonably well. Previous values of α for ϕ production range from 0.62 to 0.86, depending on the p_t range studied. In this experiment, the liquid argon calorimeter from E706 is used to provide transverse energy information. The mean p_t for ϕ mesons increases with increasing E_t, as does the ratio $N(\phi)/N(\rho + \omega)$. In fact, the ratio of the dimuon mass spectra in high over low E_t events rises from with mass, confirming that high q^2 processes are correlated with larger transverse momentum production. However, it is important to note that the data set is dominated by hadron Be events, so momentum conservation may be an important component of this result. Analysis of data on heavier targets is currently underway.

STRANGENESS PRODUCTION

The production of particles including a strange quark has been predicted to increase if a quark gluon plasma is formed, due to the large abundance of s-quarks in an equilibrated plasma. This was discussed by Peter Koch in his theoretical overview of strangeness production. However, he reminded us that a hadron gas in equilibrium will also produce large numbers of strange particles, so this signal is not easy to interpret. Enhancements of kaons and lambdas in nucleus-nucleus over p-p collisions may arise from final state interactions. Secondary collisions also increase the $\phi/(\rho+\omega)$ ratios; in fact, a purely hadronic scenario can describe the ratio observed by NA38.

However, Johann Rafelski argued that strange antibaryons provide a cleaner signal than kaons or lambdas. Recent measurements by WA85 yield a ratio of anticascades to antilambdas 10 times larger in S+W collisions than in p-p. Rafelski claims quark-gluon plasma formation is the only possible explanation for an enhancement of this magnitude. The multiplicity dependence of the enhancement is currently being studied by WA85, and should help to constrain the interpretation of the result.

The experimental situation at 14.5 GeV/nucleon was reported by Yasuo Miake for the E802 collaboration. He reminded us that the ratio of K^+/π^+ is significantly enhanced in central Si+Au collisions, compare to p+Be. The ratio in p+Au also shows an enhancement, but less than in Si+Au. The rapidity distributions of pions, kaons and protons in the three cases show that the number of kaons is enhanced, and they are peaked near target rapidity in p+Au and Si+Au. This strongly suggests production of additional K^+ by secondary collisions. The magnitude of the effect increases with multiplitity in p+Au.

Kam-Biu Luk reviewed strange hyperon and K_s^0 production in proton-nucleus collisions. K/Λ and Λ/Λ ratios show no dependence on A or p_t; the available results are not, however, at low rapidities where rescattering effects could be important. Values of α are $<$ 1 for p_t $<$ 2 GeV/c, then rise to approximately 1. The rapidity distributions of K_s^0 and Λ^0 suggest that heavier targets cause depletion of higher momentum particles; the effect is much larger for lambdas than for kaons. Quark models with multiple collisions describe this observation fairly well.

JETS AND MINIJETS

Jets might provide a unique probe of dense matter in heavy ion collisions at large $\sqrt{s}$. In the plenary session, Gyulassy suggested that jets may serve as "external" probes of nucleus-nucleus collisions as they are produced prior to any plasma formation, at rates which can be calculated with perturbative QCD. The jet distributions may yield information about the hot, dense sytem, as the energy loss of jets in a quark gluon plasma should be considerably smaller than in hadronic matter.

Xin Nian Wang discussed the importance of jets and minijets in high $\sqrt{s}$ collisions. He reminded us that production of minijets should be quite copious in nucleus-nucleus collisions, and they will contribute to transverse energy and particle production, as well as modify the observed p_t distributions. Minijets may also help accelerate thermalization by increasing the number of soft particles produced. He introduced a model, HIJING, that incorporates QCD hard and semi hard processes and successfully reproduces the single particle distributions in collider and high energy p nucleus data. HIJING also includes nuclear shadowing of the parton distributions, and allows hadronic jet quenching to be turned on or off. Using HIJING, one may then address the best way to look for modification of jets at the relativistic heavy ion collider. Wang concluded that effects of parton shadowing and jet quenching may be measured via the single particle distributions for $p_t > 2\text{-}3$ GeV/c. Comparison of p-p, p-nucleus and nucleus-nucleus collisions should allow disentangling of these processes.

Experimental studies of hard scattering in nuclei were reviewed by Marge Corcoran, who presented results on dijet production from FNAL E609 and E557, dihadron production from E711 and single and di-hadrons from E605/E789. Comparing dijets in p+Pb and p+p collisions, we see that the nucleus causes a large shift of the angle between the jets away from coplanarity. Such an effect would arise from parton multiple scattering. Looking at the A dependence of jet and single high p_t particle production from nuclear targets, she concluded that $\alpha > 1$, and falls with $\sqrt{s}$ and p_t. However, comparison of different experiments is complicated by the fact that the extracted value of α is a strong function of the kinematical cuts. The internal structure of the jet, as manifested by its fragmentation, is affected only slightly, if at all, by the nucleus. All of these observations are consistent with a multiple scattering picture in which fragmentation occurs outside the nucleus. These results support the idea that jets are sensitive to the nuclear environment, but their fragmentation is not affected by it. Consequently, they may prove to be useful probes of the early stages of nucleus-nucleus collisions.